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(54) Microcomputer based fault detection and indicator control system in a refrigeration apparatus

(57) A fault detection and indicator control system in a refrigeration apparatus includes a microprocessor (46) responsive to various sensing means (61–75) for controlling the operation of a display device to indicate specifically the various types of faults. A communication network (49) is operatively connected to the microprocessor (46) for automatically dialling up a service man in the event of certain malfunctions. The microprocessor (46) can also transmit the particular fault code representative of the specific failure so as to facilitate repair of the apparatus by the service man.

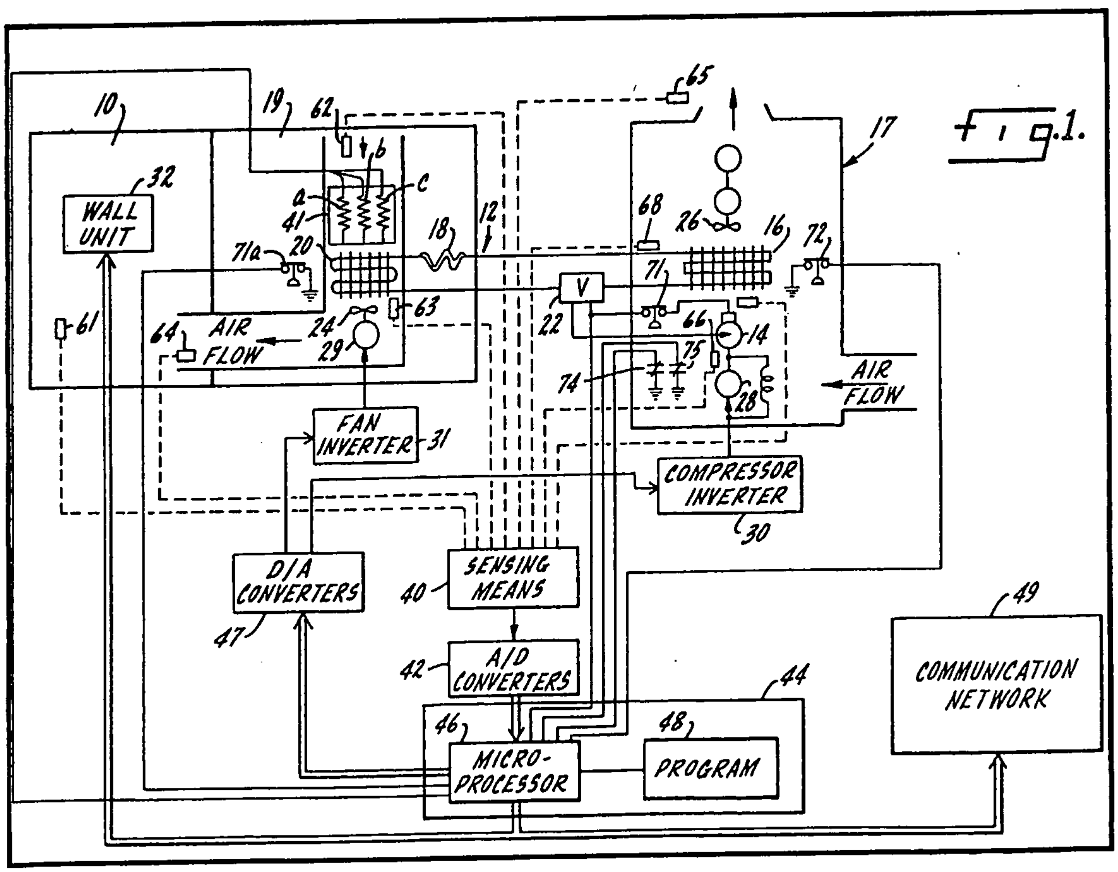

Fig.1.

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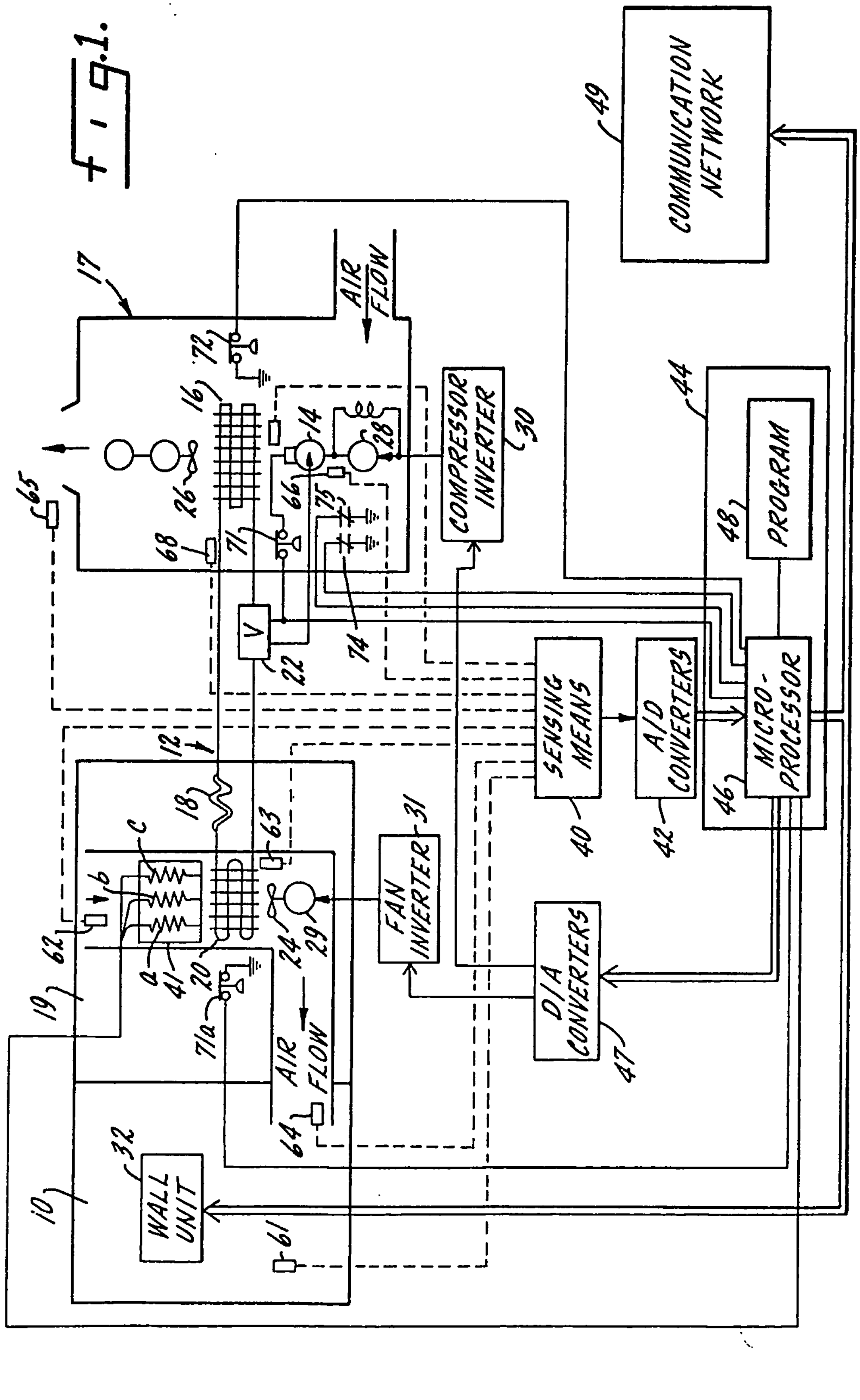

Fig.1.

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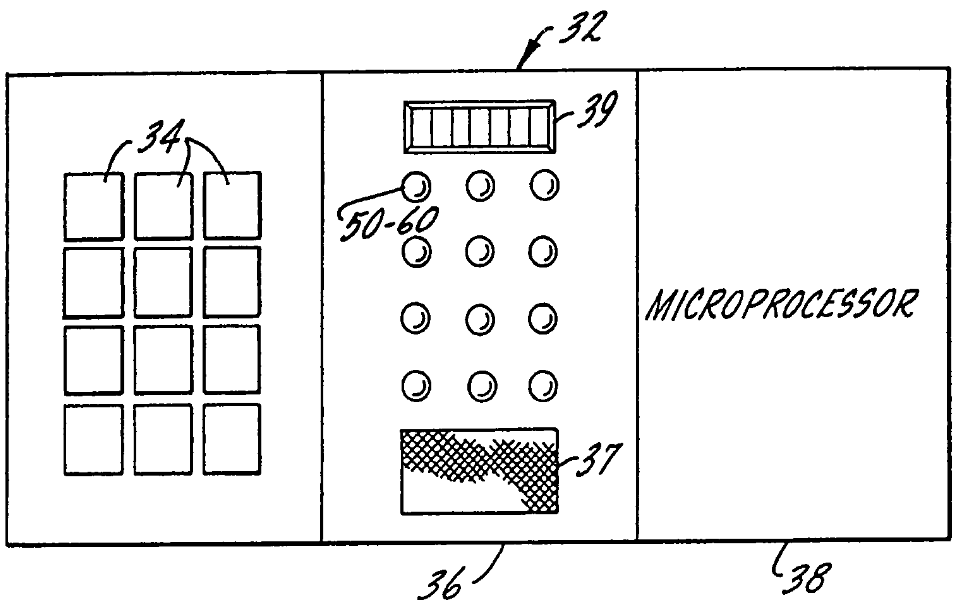
Fig.2.



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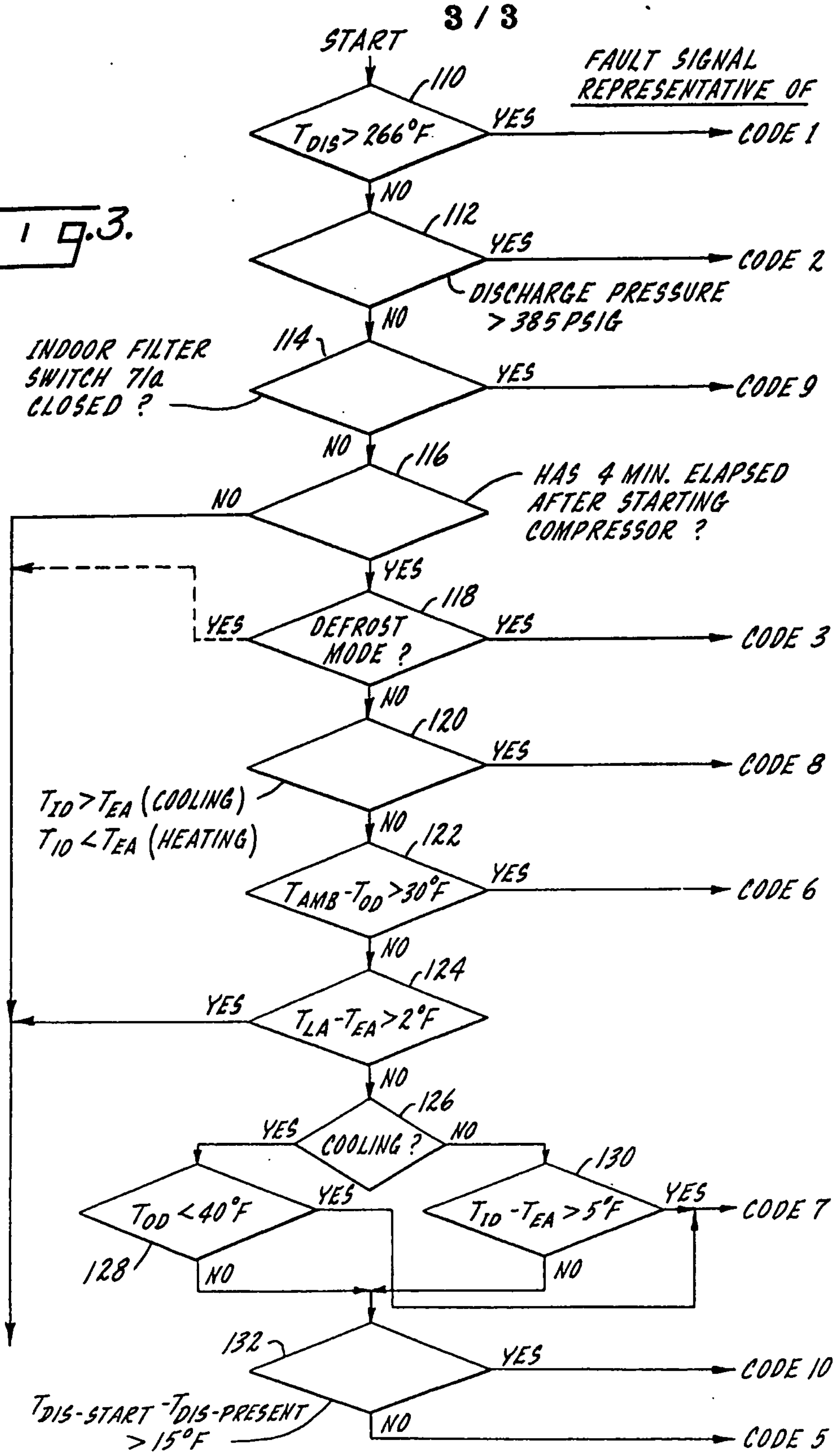

Fig. 3.

SPECIFICATION

Microcomputer based fault detection and indicator control system

1. Field of the Invention:
This invention relates generally to refrigeration apparatus and more particularly, it relates to a microcomputer-based fault detection and indicator control system for use in an air conditioning or refrigerating apparatus for monitoring continuously and for displaying of fault codes when the apparatus encounters certain malfunctions. The invention has specific application to reversible heat-pump apparatus operable for cooling and heating residential dwellings, small office buildings, mobile homes and the like.

2. Description of the Prior Art:
In U.S. Patent No. 4,034,570 issued on July 12, 1977 to R. M. Anderson et al, there is disclosed a control system for use in central air conditioning systems which monitors the operation thereof and provides an indication to the user of different malfunctions of the system when they occurred. Particularly, the control system prevents operation of the compressor in the event of a low voltage condition and/or a high current. The control system includes a first sensor located near the compressor shell on the suction line for detecting a low temperature so as to de-energize the compressor before freeze-up occurs. A second sensor attached to the condenser return bend was also provided to prevent operation of the refrigeration apparatus in the event of high discharge pressures.

Heretofore, it has been encountered generally that during various times of operation in such refrigeration apparatus malfunctioning problems occur which cause the apparatus to become shut down due to any number of reasons. Only some of these problems have generally required the calling of a service man to come out to the user's place while many of the other problems could be readily corrected by the user himself. However, since the specific problem or problems which cause the shut down were not known due to the fact that no means were available for the user to identify the source of trouble the user would always call the service man. Furthermore, if the malfunction was indeed of the type to be handled by the service man he had to expend time-assuming efforts in locating the problem before he could start his repair.

It would, therefore, be desirable to provide a new and improved control system for use in an air conditioning or refrigeration apparatus for monitoring continuously and for displaying of fault codes when the apparatus encounters certain malfunctions. However, the fault codes are only displayed when the malfunction is of the nature which requires the need of a service man. Otherwise, the user is allowed to restart the apparatus himself without the assistance of the service man. Once the fault codes are displayed, it would be desirable to prevent further attempts by the user to restart the apparatus by locking out the compressor. It would also be expedient to provide a fault detection and indicator control system having a microprocessor responsive to various sensing means to determine and identify specifically the type of fault. In case of a fault, a communication network could be provided so that the microprocessor could automatically dial up a service man and transmit the particular code representative of a specific failure so as to facilitate repair of the apparatus by the service man.

Accordingly, it is a general object of the present invention to provide a new and improved microcomputer-based fault detection and indicator control system for use in an air conditioning or refrigerating apparatus for monitoring continuously and for displaying of fault codes when the apparatus encounters certain malfunctions.

It is another object of the present invention to provide a microcomputer-based fault detection and indicator control system having means for displaying visually the various fault codes.

It is another object of the present invention to provide a fault detection and indicator control system having a microprocessor for controlling a display device to indicate the various fault codes in response to a plurality of sensing means.

It is still another object of the present invention to provide a fault detection and indicator control system having a first microprocessor responsive to sensing means for transmitting fault signals to a second microprocessor which controls a display device to indicate the various malfunctions.

It is yet still another object of the present invention to provide a fault detection and indicator control system which includes a microprocessor for generating fault signals and a communication network connected to the microprocessor for automatically dialing up a service man when there is a malfunction, the microprocessor transmitting also the particular fault code.

In accordance with these aims and objectives of the instant invention, there is provided a refrigeration apparatus for conditioning a space and having a closed refrigerant circuit including a compressor, a first heat exchanger, an expansion device, and a second heat exchanger connected respectively in series. The refrigerating apparatus includes a fault detection and indicator control system consisting of sensing means, fault detection control and logic means,

and display means. The sensing means includes temperature-sensitive means for measuring the temperature of the air entering the indoor unit, the coil temperature of the second heat exchanger, the temperature of the air leaving the indoor unit, the outdoor atmospheric temperature, the temperature of the oil in the crank-case of the compressor, the high discharge temperature from the compressor, and the coil temperature of the first heat exchanger. The sensing means further include pressure-activated switches associated with high discharge pressure from the compressor, a clogged or dirty filter in the second heat exchanger, and a defrost mode, a motor protector contactor for interrupting operation of the compressor due to high currents and a pair of relay contacts for determining whether failure is due to the high discharge pressure or opening of the motor protector contactor. The fault detection control and logic means is operatively connected to the sensing means and is responsive thereto for controlling the display means to indicate the various fault codes.

A telephone communication network can be operatively connected to a microprocessor in the logic means for automatically dialing up a service man in the event of certain malfunctions. The microprocessor will also transmit the specific fault codes via the communication network directly to the location where the service man is being called.

One way of carrying out the invention is described in detail below with reference to drawings which illustrate only one specific embodiment, in which:—

Figure 1 is a block diagram of the refrigeration apparatus having microprocessors, according to the present invention;

Figure 2 is a plan view of the wall unit in the fault detection and indicator control system embodying the present invention; and

Figure 3 is a flow chart showing an exemplary checking procedure in the refrigerating apparatus of the present invention for indicating the various fault codes.

Referring now in detail to the drawings, there is shown in Fig. 1 a conditioned space or zone 10, which may be a room or rooms of a residential dwelling, that is provided with a refrigeration apparatus designated generally by reference numeral 12. The refrigeration apparatus 12 consists preferably of a conventional reversible heat-pump type which includes a compressor 14, a first heat exchanger 16 located normally outside and away from the conditioned space 10, an expansion valve 18 such as a capillary tube, and a second heat exchanger 20 arranged in fluid communication with the zone 10 connected respectively in series to form a closed refrigerant circuit. As can be seen, the compressor 14 and the first heat exchanger 16 are housed in an outdoor unit 17 while the expansion device 18 and the second heat exchanger 20 are arranged within an indoor unit 19. During the cooling cycle or mode of operation, the first heat exchanger 16 is functioning as a condenser and the second heat exchanger 20 is operating as an evaporator. The refrigeration apparatus also includes a four-way reversing valve 22 for reversing the direction of refrigerant flow in the first and second heat exchangers so that the first heat exchanger is operated as an evaporator and the second heat exchanger is functioning as a condenser. When the system is made to operate in this reverse manner, this is generally referred to as the heating cycle or mode. The manner of controlling the position of the valve 22 may be conventional and is not shown.

An indoor fan 24 is positioned within the indoor unit 19 in the vicinity of the second heat exchanger 20 for circulating air therethrough and into the conditioned space 10. An outdoor fan 26 is also arranged in the outdoor unit 17 adjacent the first heat exchanger 16 for circulating of the air therethrough and out into the atmosphere. The ducts necessary to supply the conditioned air to the space 10 to be cooled or heated and to remove the respective heated or cooled air to the atmosphere have not been shown. The compressor 14 is driven by a variable-speed electric motor 28 whose speed is controlled by a motor speed control means such as a compressor inverter 30. The inverter 30 may be of any conventional type well-known in the art and is utilized to provide an A-c voltage which is of a varying amplitude and frequency. It should be noted that the change in the speed of the motor and thus the compressor speed are directly proportional to the changes in the frequency within the standard speeds of operation. Similarly, the indoor fan 24 is driven by a variable-speed electric motor 29 which is controlled by a second motor speed control means such as indoor fan inverter 31.

The refrigeration apparatus is provided with a wall unit 32 located at a suitable place within the conditioned space 10. As can best be seen from Fig. 2, the wall unit 32 includes a plurality of manually-operated switches 34 for setting desired conditions within the space to be controlled, i.e., the desired temperature of the space. Some of the other switches 34 may be utilized to select the on-off condition of the apparatus and the heating or cooling mode of operation. The wall unit 32 also includes a visual and/or sound display device 36 for indicating or warning the user of a malfunction of the apparatus and a first microprocessor 38 for controlling the operation of the display device 36. The display device 36 consists of a plurality of indicator lights, an audible alarm unit 37, and an alphanumeric display unit 39.

Normally, an illuminated digital representation of the actual measured temperature of the conditioned space 10 is displayed on the display unit. However, the representation can be

selectively changed by depressing appropriate switches 34 to provide other related information of the apparatus such as pre-set reference temperatures of the conditioned space at particular times of the day.

The refrigeration apparatus further includes sensing means 40 for generating electrical signals representative of conditions within the apparatus. Analog-to-digital converters 42 are connected to the outputs of the sensing means 40 for producing digital signals which are delivered to a fault detection control and logic device 44. The device 44 consists of a microprocessor 46 having a program 48 for continuously monitoring and controlling the overall operation of the refrigeration apparatus by allowing reading of input signals from the sensing means 40 and for providing appropriate output faults signals to the microprocessor 38 in the wall unit 32 through interconnected wires for activating the display device 36. The second microprocessor 46 controls the operation of the system by varying the speeds of the indoor fan 24 and compressor 28 by means of digital-to-analog converters 47 and the respective fan inverter 31 and compressor inverter 30.

It should be understood that while the microprocessors 38 and 46 have been shown, the present invention can also be implemented with various solid-state electronic components such as discrete logic circuit chips interconnected to perform the desired function. The microprocessors 38 and 46 illustrated in Fig. 1 may be of any one of a number of general purpose programmable digital computers which are commonly available at present.

As can be seen from Fig. 2, the display device 36 includes a plurality of indicator lights 50–60, each of which being illuminated a different malfunction of the apparatus. Each of the lights is associated with a particular malfunction of fault code. A table is provided below to show the code number and the fault associated therewith:

CODE	FAULT
1	High Discharge Temperature
2	High Discharge Pressure
3	More Than One Defrost in 5 Minutes
4	Emergency Heat
5	Compressor or Inverter Failure
6	Outdoor Air Flow Loss (On Heating)
7	Indoor Air Flow Loss
8	Reversing Valve Failure
9	Dirty Indoor Filter
10	Partial Loss of Charge

Referring again to Fig. 1, the fault detection control and logic device 44 receives various input information from different portions of the apparatus 12 through the sensing means of 40 and provides fault code signals for controlling illumination of lights 50–60 and sounding of the alarm unit 37 by means of the microprocessor 38. Illustratively, the sensing means 40 includes a plurality of measuring means consisting of temperature-responsive means such as thermistors 61–70, pressure switches 71, 71a, 72, motor protector contactor coil 73 and a pair of relay contacts 74, 75. The thermistor 61 produces an analog electrical signal which is proportional to and representative of the present actual measured temperature in the conditioned space 10 where the temperature is to be controlled. The thermistor 61 may be located at any convenient location within the conditioned space. The thermistor 62 is positioned within the indoor unit 19 adjacent the entering duct and produces an analog electrical signal which is proportional to and representative of the temperature of the air entering the indoor unit. The thermistor 63 is located on the return bend of the coil of the second heat exchanger 20 for sensing the temperature thereof. The thermistor 63 produces an analog electrical signal which is proportional to and representative of such second heat exchanger coil temperature. Further, the thermistor 64 is located within the indoor unit 19 adjacent the exiting duct for sensing the temperature of the air leaving the indoor unit. The thermistor 64 produces again an electrical analog signal which is proportional to and representative of the leaving air temperature of the indoor unit 19.

Referring to the outdoor unit 17, the thermistor 65 produces an analog electrical signal which is proportional to and representative of the present actual measured outdoor atmospheric temperature. The thermistor 66 is located near the crankcase of the compressor 14 so as to sense the temperature of the oil therein. The thermistor 67 is positioned on the discharge line of the compressor 14 and senses the high discharge temperature thereof. The thermistor 68 is located on the return bend of the first heat exchanger 16 and senses the coil temperature too thereof which is referred to as the liquid line temperature TOD when the apparatus is operated in the cooling mode.

The pressure-activated switch 71 is in series with the high discharge line of the compressor 14 which opens up on sensing of high pressure. The second pressure-activated switch 71a is

associated with the second heat exchanger 20 which closes when the indoor filter is dirty or clogged. The third pressure-activated switch 72 is associated with the first heat exchanger 16 to provide an indication that the apparatus is in the defrost mode. The motor protector contactor coil 73 is provided across the motor 28 which interrupts the operation of the compressor in the event of a high starting current, which may cause damage to the motor. The relay contact 74 and the relay contact 75 are provided to supply input signals to the microprocessor 46 so that it can determine whether a failure is caused by opening of the motor protector contact or due to high discharge pressure in the compressor. If relay contact 74 is opened alone or if both relay contacts 74 and 75 are opened, then the failure was due to the motor protector contactor opening. On the other hand, if relay contact 74 is closed and the relay contact 75 is opened, the failure was due the high discharge pressure.

In order to understand the operation of the microprocessor-base fault detection and indicator control system, an illustrative checking and/or monitoring procedure will now be described. It should be clearly understood that there are considerable variety in the detailed steps by which the fault detection objectives can be achieved through the use of the microprocessors 38, 46. Thus, the following example to be described will be appreciated by those skilled in the art to be but only one of the possible sequences of suitable steps. In order to facilitate the ease of understanding, reference is now made to Fig. 3 of the drawings which is a decision flow chart and the table previously mentioned describing the various fault codes. Initially, prior to allowing the compressor to be turned on the difference between the oil temperature Toil in the crankcase as sensed by the thermistor 66 and the outdoor temperature Tamb as sensed by the thermistor 65 is compared with the outdoor temperature Tamb to check to see if it is greater than a predetermined amount. This insures that the refrigerant is out of the oil and the oil temperature Toil is high enough so as to avoid possible damage to the compressor. If this condition is met, the compressor 14 is allowed to be turned on.

With the compressor 14 in the running condition, the operating conditions are checked by starting at the first decision block element 110 of the flow chart in Fig. 3. In the element 110, the temperature ^{T}dis of the high discharge of the compressor as sensed by the thermistor 67 is compared with a reference temperature stored in the microprocessor 46. Typically, the reference temperature is set at 266°F. If the discharge temperature ^{T}dis is greater than 266°F, a fault signal representative of fault code number 1 is generated by the microprocessor 46. If the discharge temperature ^{T}dis is equal to or less than 266°F, then the next item to be checked is shown in decision block 112. In the block 112, the microprocessor 46 senses whether the high pressure switch 71 is opened or closed. If it is opened signifying a pressure greater than 385 psig. a fault signal representative of fault code number 2 is produced by the microprocessor 46. If the discharge pressure is equal to or less 385 psi, then the checking proceeds to element 114. In the decision block element 114, the pressure-activated switch 71a is checked by the microprocessor to be in the opened or closed position. If the indoor filter switch 71a is closed, this indicates a dirty filter. This fault code number 9 will not shut down the compressor and can be reset as soon as the filter is replaced.

In order to ensure that the system is approaching normal operating conditions, all further checks are not made until a period of such as four minutes has elapsed. This is accomplished by the decision block element 116. If there has not been four minutes of running time on the compressor, no further checks are made. After the element 116, the system is checked to determine whether it is in the defrost mode and whether less than five minutes have passed since the last defrost. If there has been a defrost within the last five minutes or is in defrost, no further checks are made which is controlled by block element 118. If the system is not in defrost, then the checking proceeds to block element 120.

In block 120, the system is checked to determine whether the reversing valve 22 has failed. In the cooling mode, this is done by comparing the temperature TID of the indoor coil or second heat exchanger as sensed by the thermistor 63 with the temperature TEA of the air entering the indoor unit 19. If the indoor coil temperature TID is greater than the entering temperature TEA, a fault signal representative of the fault code number 8 will be generated to indicate a reversing valve failure. In the heating mode, a failure is indicated when the indoor coil temperature TID is lower than the temperature TEA of the air entering the indoor unit 19. If the condition of element 120 is not satisfied, then the checking proceeds to decision block element 122. Here, if the system is in the heating mode, the difference between the outdoor temperature Tamb, as sensed by the thermistor 65 and the liquid line temperature TOD as sensed by the thermistor 68 is checked to determine if it is greater than 30°F. If this is true, then a fault signal representative of the fault code number 6 is generated thereby indicating outdoor air flow loss during the heating cycle. In element 124, the temperature TLA of the air leaving the indoor unit as sensed by thermistor 64 is compared with the temperature TEA of the air entering the indoor unit, taking into account whether the system is operated in the heating or cooling mode. If the difference is not greater than 2°F, this is an indication that there is some problem. Then, the checking proceeds to element 126. If there was no indication of a problem, no further fault

checks would be made.

In the block element 126, it is determined whether the system is in the cooling mode. If the system is in cooling, block element 128 is used to determine whether the liquid line temperature TOD is less than 40°F. If this condition is true, then a fault signal representative of fault code number 7 is produced to indicate an indoor airflow loss on cooling. If the liquid line temperature TOD is above 140°F, then the check continues on to element 132 to determine whether there is a loss of charge or a compressor or inverter failure. If the block element 126 had indicated that the system was in the heating mode, the difference between the indoor coil temperature TID and the temperature TEA of the entering air must be greater than 5°F. This would cause also a fault signal representative of the fault code number 7 to be generated for indicating an indoor airflow loss which is determined from the block element 130. If either the condition from block 128 or block 130 is not true, then two additional checks are made in the block element 132 to determine whether there has been a partial loss of charge. This is accomplished by comparing the discharged temperature of the compressor after it has been running four minutes with the present discharged temperature. If there is a difference of 15° or more, then a fault signal representative of the fault code 10 will be generated to indicate that there is a partial loss of charge. If this condition is not true, then a fault signal representative of fault code number 5 will be produced to indicate that there is a compressor or inverter failure since the discharge temperature has remained substantially unchanged.

In addition, a microprocessor 46 has been programmed by the program 40 to automatically start the system in the cooling mode when the outdoor temperature Tamb. as sensed by the thermistor 65 is greater than 85°F and to automatically start the system in the heating mode when the outdoor temperature Tamb. is less than 85°F. Further, in case of a failure of the microprocessor, electric heaters 41a–41c are automatically turned on and the fault code number 4 will become illuminated. The microprocessor 46 has been programmed so that only after three fault signals has been produced in a 24 hour period will the indicator lights become lighted. Thus, the user will then know that it is time to call a service man. Further, after three faults of any kind listed in the table, except for fault code number 9, the compressor will be locked out so as to prevent attempts by the user to restart the apparatus. Otherwise, the user is allowed to restart the apparatus after a failure thereby avoiding the costly service from the service man. A telephone communication network 49 can also be operatively connected to the microprocessor 46 for automatically dialing up the service man in the event of a malfunction. In addition, the microprocessor 46 will also transmit the particular code representative of the last specific failure so as to facilitate repair of the apparatus by the service man.

The microprocessor 46 will transmit the fault signals to the microprocessor 38 located in the wall unit 32. The microprocessor 38 responsive to the faults signals will cause the illumination of the indicator lights 50–60 at the appropriate times. It should be understood that a single microprocessor could have been utilized, if desired, to perform all of the above monitoring and fault indicating procedures.

From the foregoing detailed description, it can thus be seen that the present invention provides a new and improved fault detection and indicator control system having a microprocessor responsive to various sensing means for controlling the operation of a display device to indicate the various fault codes. Further, the present invention is provided with a communication network for automatically dialing up a service man in the event of certain malfunctions.

While there has been illustrated and described with reference to what is considered at present to be a preferred embodiment of the present invention, it will be understood by those skilled in the art that various changes and modifications may be made and equivalents may be substituted for elements thereof without departing from the true scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the central scope thereof. Therefore, it is intended that this invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention will include all embodiments falling within the scope of the appended claims.

CLAIMS

1. A refrigeration apparatus for conditioning a space and having a closed refrigerant circuit including a compressor, a first heat exchanger, an expansion device, and a second heat exchanger connected respectively in series, the compressor and the first condenser being contained in an outdoor unit, the expansion device and the second heat exchanger being contained within an indoor unit, said apparatus including fault detection and indicator control system for monitoring continuously and for displaying of fault codes when the apparatus encounters certain malfunctions comprising in combination:

sensing means including temperature-sensitive means for measuring the temperatures of the air entering the indoor unit, the coil temperature of the second heat exchanger, the temperature of the air leaving the indoor unit, the outdoor atmospheric temperature, the temperature of the

oil in the crankcase of the compressor, the discharge temperature from the compressor, and the coil temperature on the first heat exchanger;

said sensing means further including pressure-activated switches associated with high discharge pressure from the compressor, a clogged or dirty filter in the second heat exchanger and a defrost mode, motor protector contactor and a pair of relay contacts;

fault detector control and logic means operatively connected to sensing means and responsive thereto for controlling display means to indicate fault codes;

display means operatively connected to said fault detector control and logic means for displaying various fault codes; and

said fault detector control and logic means including means for storing a plurality of reference temperatures, means for calculating various temperatures to be stored in response to said sensing means, and means for comparing said calculated temperatures with respective reference temperatures to generate fault signals to said display means.

2. A refrigeration apparatus as claimed in Claim 1, wherein said temperature-sensitive means comprises thermistors.

3. A refrigerating apparatus as claimed in Claim 1, further comprising alarm means operatively connected to said fault detection control and logic means for providing a sound warning when there has been a fault code.

4. A refrigerating apparatus as claimed in Claim 1. wherein said fault detector control and logic means comprises a first microprocessor having a program.

5. A refrigerating apparatus as claimed in Claim 4, further comprising manually-operated switch means for supplying various inputs to said first microprocessor.

6. A refrigerating apparatus as claimed in Claim 5, wherein a microprocessor is provided for controlling the operation of the display means in response to fault signals generated by said first microprocessor.

7. A refrigerating apparatus as claimed in Claim 1, wherein communication network means is operatively connected to said fault detection control and logic means for automatically dialing up a service man in the event of certain malfunctions.

8. A refrigerating apparatus as claimed in Claim 1. further comprising what has been described and shown in reference to the drawings.

9. A refrigeration apparatus as claimed in Claim 1, wherein said fault detection and indicator control system means perform a checking monitoring procedure in accordance with the flow chart shown in Fig. 3 of the drawings.

10. A refrigerating apparatus as claimed in Claim 1, wherein said apparatus is substantially identical to the York Advanced Heat Pump System.

11. A refrigeration apparatus constructed and arranged to operate substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

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